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## Collembola in Norwegian coniferous forest soils

### III. Relations to soil chemistry

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With 3 figures

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#### 1. Introduction

This paper is the third in a series on the ecology of Collembola in Norwegian coniferous forest soils. The first paper dealt with relations to plant communities and soil fertility (HÅGVAR 1982), and the second with the vertical distribution (HÅGVAR 1983).

Norwegian coniferous forest soils range from very shallow and poor iron podzols to deep and fertile brown earth (from Typic Udipsamment to Aquic Haploboroll, USDA classification). Several chemical parameters vary greatly between these soils. The present paper deals with the relationship between abundance of various Collembola species and the chemical properties of the soil. Both from an ecological point of view and in order to assess the value of Collembola species as soil quality indicators, this represents an interesting field of study. Earlier Norwegian experiments have, for instance, indicated that the abundance of certain Collembola species is related to soil acidity (HÅGVAR & ABRAHAMSEN 1980, HÅGVAR & KJØNDAL 1981b, HÅGVAR 1984). This hypothesis needs to be tested under field conditions.

The first author is responsible for the faunistic and pedological data, while the second author performed the statistical analyses.

#### 2. Description of habitats

In each of two study areas (A and B) in SE Norway, the Collembola fauna was studied in seven different vegetation types. Ranged according to increasing soil fertility, the vegetation types were as follows: (1) Cladonio-Pinetum (*Cl-Pn*); (2) Barbilophozio-Pinetum (*Ba-Pn*); (3) Vaccinio-Pinetum (*Va-Pn*); (4) Eu-Piceetum Myrtilletosum (*Eu-Pc My*); (5) Eu-Piceetum Dryopteris (*Eu-Pc Dr*); (6) Melico-Piceetum typical (*Me-Pc ty*); (7) Melico-Piceetum Athyrium (*Me-Pc At*).

In study area A, two *Me-Pc At* localities were investigated (named A1 and A2). The soil in A2 was unusually fertile, with a base saturation of about 80% and a soil pH of about six.

The two most fertile vegetation types (*Me-Pc ty* and *Me-Pc At*) usually have a brown earth with mull humus, while ironpodzol with raw humus is characteristic of the poorer sites. Exceptions from this pattern were a granular raw humus in the *Me-Pc ty* habitat of area B, a brown earth in the *Eu-Pc Dr* habitat of area A, and a peat soil in the *Ba-Pn* locality of area A.

Detailed descriptions of the habitats are given by HÅGVAR (1982).

To simplify comparisons between habitats and study areas, a number of soil chemical parameters have been presented graphically in Fig. 1.

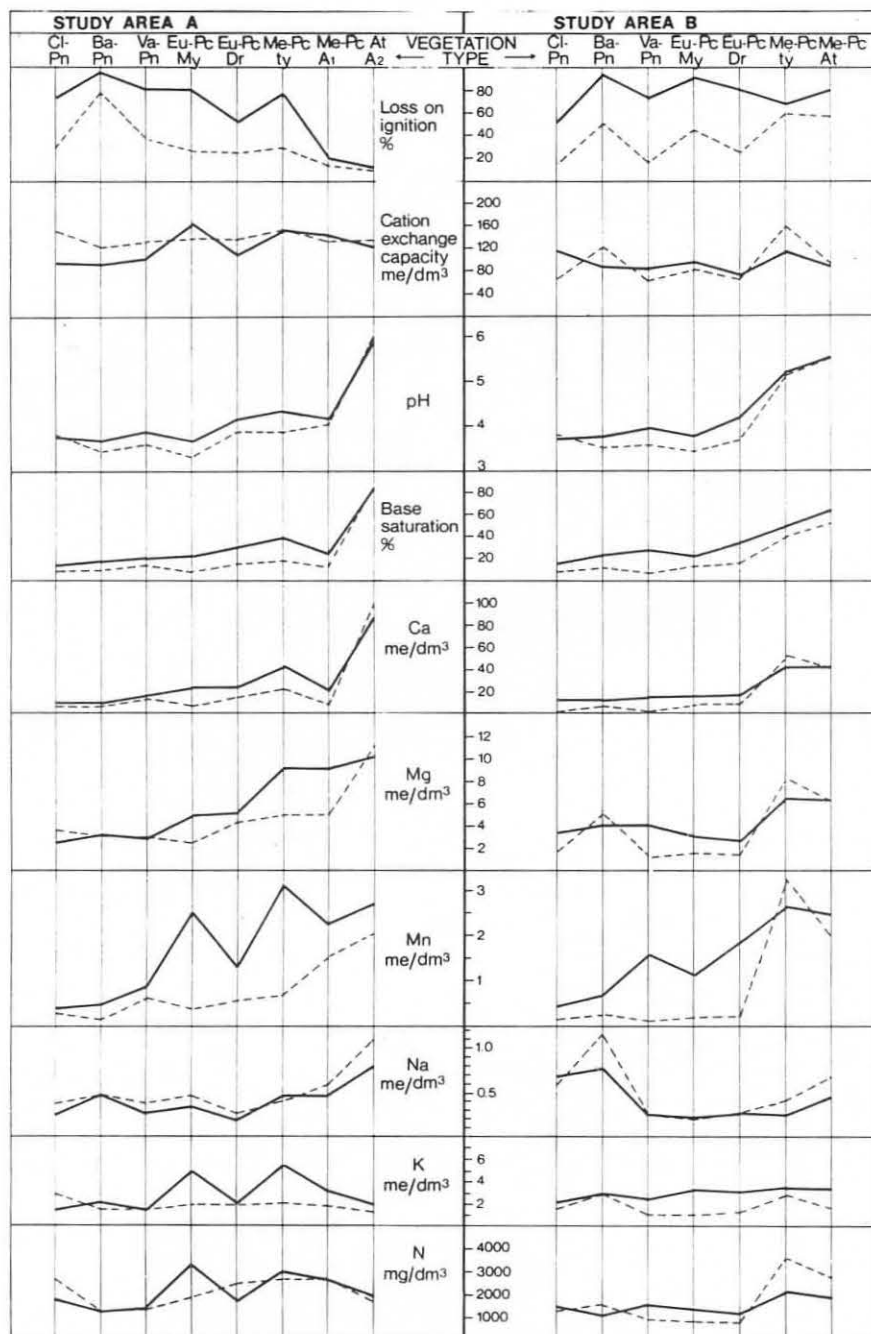


Fig. 1. Soil chemical parameters in the different habitats. In each study area, the plant communities have been ranged according to increasing soil fertility. Bold lines: 0—3 cm depth, stippled lines: 3—6 cm depth.

### 3. Materials and methods

HÄGVAR (1982) presented detailed information on sampling and extraction of Collembola, as well as comments on taxonomy. In each of the fifteen habitats, sampling was performed in spring (May/June) and autumn (Aug./Sept.). One sampling in a given habitat consisted of twenty soil cores of 10 cm<sup>2</sup>. The distribution of each Collembola species on the different habitats and soils at each season appears from Table 4 and Figs. 8 and 9 in HÄGVAR (1982).

The extracted, dried soil cores from the autumn sampling were pooled for each habitat and used for chemical analyses. The procedure for these analyses was described by ÖGNER *et al.* (1975, 1977). According to this, soil pH was measured in a soil: water suspension of 1: 2.5. Cation exchange capacity was based on ammonium acetate (pH 7) extraction. The concentrations of cations represent exchangeable amounts. Nitrogen concentration is total N.

Because the abundance of most Collembola species is low below 6 cm depth (HÄGVAR 1983), the present analysis has been restricted to the 0–3 and 3–6 cm layers.

The relationship between Collembola numbers and soil chemical properties of the various vegetation types was tested on a volume basis. The number of animals was per m<sup>2</sup> in each depth level, and the concentration of chemical compounds was per dm<sup>3</sup>. The statistical analysis was based on various procedures. Relationships were first analysed by multiple regression analysis with number of animals as the dependent variable. Calculations of correlation coefficients were also carried out. These analyses did not give consistent results. Naturally, the most important factor in the multiple regression analysis was the same as that one best correlated to the number of animals. However, the next most important factor in the regression analysis often was not at all correlated to the number of animals. Also, within each species, different combinations of chemical factors appeared as significant at different samplings. In this way the results became very difficult to interpret. The further analysis was therefore entirely based on calculation of correlation coefficients. However, due to the low number of plant communities and the non-normal distribution of the population data, the correlation analysis was based on ranking of the parameters using the Spearman's rank correlation coefficient.

### 4. Results

Since many species showed very different densities in areas A and B, these study areas were treated separately in the statistical analyses. The material was also separated seasonally (spring/autumn) and vertically (0–3/3–6 cm) in order to exclude the effects of season and depth on the population size. In each area, this gave four possibilities of relating the abundance of a given species to the soil chemical parameters of the vegetation types. For species occurring in both areas, eight correlation coefficients were thus calculated. These eight correlation coefficients were considered to be of equal value. In fact, the two vertical layers in the same sampling might give as different results as those from different seasons. As shown in Table 1, no species achieved more than four significant correlation coefficients.

Table 1 contains those species which achieved an abundance of 1,000 ind m<sup>-2</sup> in at least one habitat. However, six "qualified" species occurring only, or almost only, in one plant community, have been deleted from the analysis. Three analysed species (*Willemia anophthalma*, *Folsomia sensilis* and *Isotoma hiemalis*) showed no significant relationships to any of the chemical properties and were for that reason excluded from the table.

The uppermost species in Table 1 occur mainly in the poorest soils, while the lower species are most abundant in richer soils (HÄGVAR 1982). The rich soils are characterized by high values of several parameters (Fig. 1). Most prominent are pH, base saturation, Ca, Mg and Mn. A number of positive correlations were found between these factors and several of the "rich soil species" in the lower part of Table 1. Conversely, relationships to these factors were negative in "poor soil species" in the upper part of the table. Loss on ignition was low in rich soils in area A (Fig. 1), giving some positive correlations with the "poor soil species", and negative correlations with certain "rich soil species" (Table 1).

In most species, significant correlations to single soil chemical parameters were found in only one, two or three of the eight possibilities. However, except for a few cases deleted from Table 1, repeated reactions to the same factors showed the same trend (either positive or negative). All the relevant species, except two, occurred in both study areas (*Hypogastrura inermis* was restricted to area A, and *Mesaphorura italica* to area B).

The most reliable relationships are those which appeared in both study areas. Such cases were found in seven species and comprised the following parameters: pH, base saturation, Ca, Mg, Mn and K (Table 1).

Table 1. Significant relationships (positive or negative) between the abundance of Collembola species and soil chemical parameters

	N	pH	Base	Ca	Mg	Mn	Na	K	IGN	In both areas:
<i>Anurophorus septentrionalis</i> PALISSA			—	—		—				
<i>Hypogastrura inermis</i> (TULLBERG)			⊖	⊖	⊖—	⊖		—		
<i>Folsomia quadrioculata</i> (TULLBERG) s. l.						—		+		
<i>Fricsea mirabilis</i> (TULLBERG)		⊖—	⊖—	⊖	—	—				—pH, —Base
<i>Onychiurus armatus</i> (TULLBERG) s. l.		—	—	—	⊖	—		+	+	
<i>Lepidocyrtus lignorum</i> (FABRICIUS)	+					+	—	++		
<i>Mesaphorura tenuisensillata</i> (RUSEK)		—	—	—				⊕	⊖	
<i>Mesaphorura yosii</i> RUSEK		⊖—	—		⊖—				⊕	—Mg
<i>Anurophorus binoculatus</i> (KSENEMAN)		⊖—			—				+	
<i>Anurida forsslundi</i> (GISIN)			—		—				++	—Mg
<i>Anurida pygmaea</i> (BÖRNER)	—				⊖—		⊖		+	—Mg
<i>Karlstejnina norvegica</i> FJELLBERG		+	+	+	⊕	⊕				
<i>Isotomiella minor</i> (SCHÄFFER)	+				+	+				
<i>Mesaphorura macrochaeta</i> RUSEK			⊕	⊕	+	⊕				
<i>Onychiurus absoloni</i> (BÖRNER)	+						—	⊕		
<i>Willemia aspinata</i> STACH		⊕+	⊕⊕++	⊕⊕⊕+	+	⊕++		+	—	+ Base, + Ca, + Mn
<i>Isotoma notabilis</i> SCHÄFFER		⊕+	⊕++++	⊕⊕++	++	+++		++		+pH, + Base + Ca, + Mn
<i>Neelus minimus</i> WILLEM			+	+	⊕+	+			⊖—	
<i>Mesaphorura sylvatica</i> RUSEK		+	⊕+	⊕	+	⊕			—	
<i>Lepidocyrtus cyaneus</i> TULLBERG	++	++	++	++	++	++		+++		+ K
<i>Mesaphorura italica</i> RUSEK								++		
<i>Isotoma olivacea</i> TULLBERG								—		

Note: Each + or — indicates a relationship found in one sampling covering 7—8 different habitats (Spearman's test).

Ringed symbols:  $p \leq 0.01$ , otherwise  $p \leq 0.05$ .

Base = base saturation %, IGN = loss on ignition. Further explanation in text.

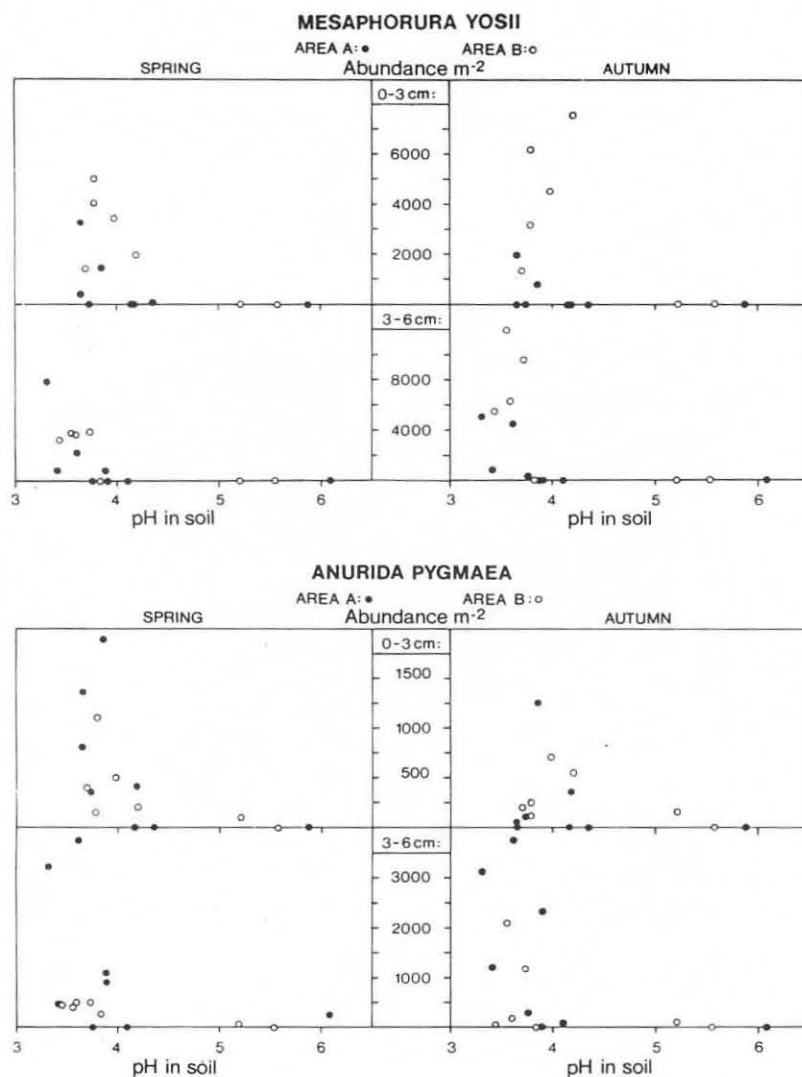


Fig. 2. Abundance of *Mesaphorura yosii* and *Anurida pygmaea* related to soil pH.

It is of special interest to look more closely at four species, which in previous experiments have reacted significantly to artificial changes in soil pH. *Mesaphorura yosii*, *Anurida pygmaea* and *Willemia anophthalma* tended to increase their abundance in acidified soil and to reduce their abundance in limed soil, while the opposite reaction pattern was observed in *Isotoma notabilis* (HÅGVAR & ABRAHAMSEN 1980, HÅGVAR & KJØNDAL 1981b, HÅGVAR 1984). Of these, *M. yosii* and *I. notabilis* repeated their "characteristic" relationship to soil pH (Table 1). In Figs. 2—3, all abundance data for the four relevant species in natural soils have been related to soil pH. The first three species show very similar patterns. Although low abundance values could be found in soils of both high and low pH, all the high values were observed in rather acid soils, with pH at or below four. Conversely, *I. notabilis* often showed high abundance in soils with high pH values, and was less abundant in the most acid soils.

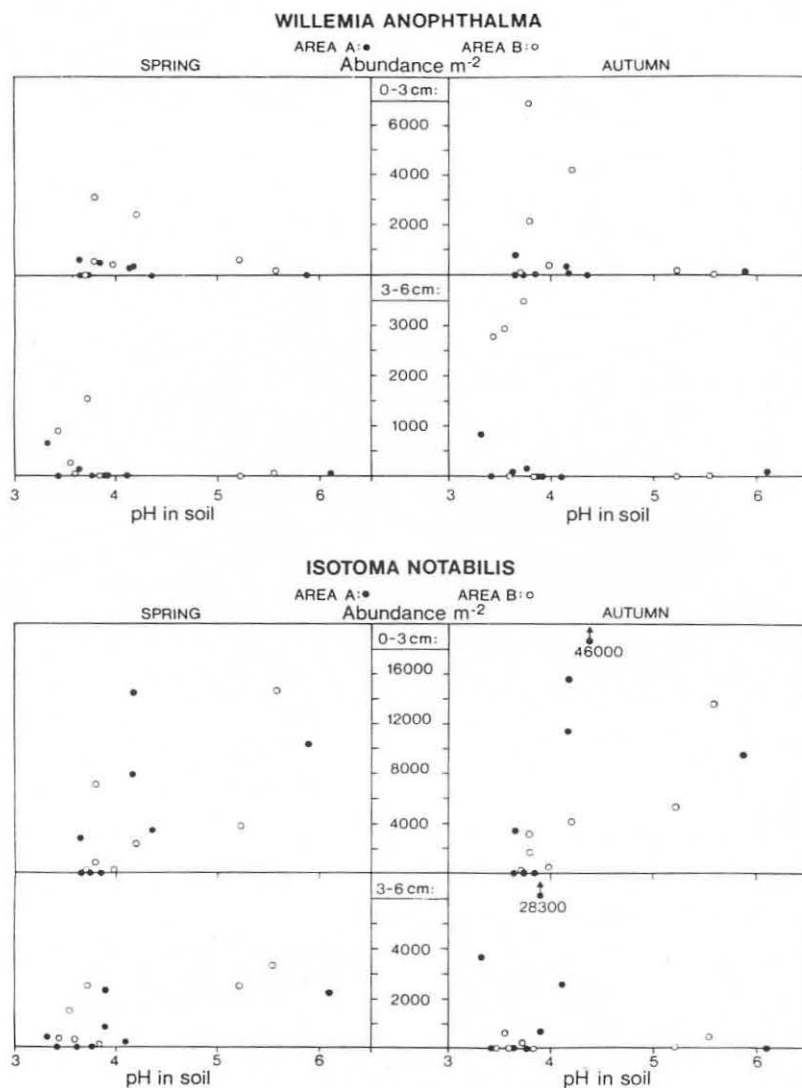


Fig. 3. Abundance of *Willemia anophtalma* and *Isotoma notabilis* related to soil pH.

### 5. Discussion

HÄGVAR (1982) showed that several Collembola species occurred mainly in poor soils, while other species were most abundant in fertile soils. It is therefore reasonable that a large proportion of the significant correlations were to parameters which changed more or less gradually with increasing soil fertility (pH, base saturation, Ca, Mg and Mn).

DAHL et al. (1967) found that pH, base saturation and nitrogen content (in % of loss on ignition) increased with increasing soil fertility in coniferous forest soils. Also in the present soils, nitrogen in % of loss on ignition was usually highest in the most fertile sites (HÄGVAR 1982). On volume basis, however, the amount of N did not increase significantly with soil fertility (Fig. 1), and few correlations were noted between Collembola and nitrogen content. However, there may be qualitative differences in the form in which N occurs. In poor soils, much of the total N is locked up in very slowly decomposing raw humus. In mull soils, a higher proportion of N may be available for microflora and animals.

There are two major problems in interpreting the present results. First, several chemical soil parameters are intercorrelated. Also physical and biological parameters such as humus type, soil porosity and microfloral composition change with soil fertility. Secondly, mathematical correlations say nothing about causal relationships. Theoretically it is possible that none of the measured parameters has any direct influence on the Collembola fauna.

The problem with intercorrelated factors may be clarified somewhat in the light of earlier acidification and liming studies. The four species in Figs. 2—3 have shown characteristic reactions to artificial changes in soil pH (HÅGVAR & ABRAHAMSEN 1980, HÅGVAR & KJØNDAL 1981b, HÅGVAR 1984). In those experiments, soil pH was changed as a consequence of a large increase in the leaching of base cations. The abundance of these species was therefore also correlated to changes in the content of base cations in the soil. However, no change in the litter-, humus- and soil type could be found, and loss on ignition and the nitrogen content appeared to be unaffected (HÅGVAR & ABRAHAMSEN 1980, HÅGVAR & KJØNDAL 1981a, b, HÅGVAR 1984, ABRAHAMSEN unpubl.). These studies indicate that the abundance of many Collembola species is significantly affected by changes in the acidity level of the soil alone. Significant correlations to N or loss on ignition in *Mesaphorura yosii* and *Anurida pygmaea* might therefore be doubtful (Table 1).

A liming experiment by HUHTA *et al.* (1983) supports the impression that soil pH probably is one of the soil chemical properties best related to Collembola. They found that increased soil pH had similar effects on microarthropods, regardless of whether it was due to liming or to fertilizers (urea or ashes with phosphorous). On the species level, the results supported the Norwegian investigations referred to above.

Spearman's test did not give significant correlations with soil pH in *Anurida pygmaea* and *Willemia anophthalma*. However, a consistent pattern seems to exist in these two and the third "acidophilic" species, *Mesaphorura yosii*: high abundances only occur in very acid soils, with pH values around or below four. For these three species, the field data in Figs. 2—3 support the following hypothesis: "Soil pH (or correlated factors) acts as a limiting factor for population size in fertile soils, but in soils with pH around four or lower, high populations may build up as long as other factors do not become limiting". A limiting factor in "pH-favourable" soils may, for instance, be drought. The three relevant species were all rare in the very acid, but dry habitat, *Cl-Pn* (HÅGVAR 1982). The hypothesis in reversed form applies to *Isotoma notabilis*. This species showed high abundance values mainly in soils with pH above four (Fig. 3) and low pH values may limit population size.

The second problem, that mathematical relationships say nothing about causal relationships, has been discussed by HÅGVAR (1984). For instance, in pure cultures, populations of *Mesaphorura yosii* do not grow faster in acidified than in limed raw humus (HÅGVAR, unpublished). The response of this species to soil pH seems to depend on the presence of other faunal elements. Competition has been suggested as a key factor; i.e. this species' success in competing with other species may in some way be related to soil pH (HÅGVAR 1984).

As Collembola live in the air-filled cavities of the soil and have a hydrophobic body surface, relationships to soil chemical parameters are probably of indirect nature. One possibility is that effects occur via the microflora, an important food source for many species. Either real preferences may exist for certain fungal species, or competition for limited resources may favour different Collembola species under different soil chemical conditions.

It is interesting to note that closely related species may show quite different relationships to soil properties. The five *Mesaphorura*-species in Table 1 illustrate this very clearly. In this genus, different species are abundant at different soil fertility levels (*cf.* HÅGVAR 1982).

We have not found any other work where the abundance of Collembola species has been correlated to a large number of soil chemical properties. GLASGOW (1939) correlated the abundance of four species of soil Onychiuridae to loss on ignition. Only one species was correlated to this factor during certain periods of the year. POOLE (1961, 1962 and 1964) has studied relationships between a number of Collembola species and the depth and mass of organic matter, but only a few species showed significant relationships to these properties.

While the abundance of some Collembola species most probably is influenced by soil pH or correlated factors, possible relationships to other soil chemical parameters have to be studied further under varying field and laboratory conditions. The present study shows, however, that Collembola cannot indicate soil chemistry as precisely as, for instance, certain plants can. Combinations of species may, however, improve the level of precision.

## 6. Acknowledgement

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## 7. Résumé

### (Collembolles édaphiques des forêts de conifères en Norvège. III. Corrélations avec la chimie des sols)

Les corrélations entre les densités de 25 espèces de Collembolles et les paramètres chimiques des sols ont été étudiées au moyen du test de Spearman. Des échantillons ont été prélevés dans sept types différents de végétation dans deux zones d'étude. Les sols variaient du podzol pauvre au sol brun riche. Les paramètres chimiques étaient l'N, le pH, la saturation en bases (%), le Ca échangeable, le Mg, le Mn, le Na, le K et la perte après ignition. Pour chaque espèce, les corrélations ont été testées huit fois, sachant que les échantillons avaient été prélevés tant au printemps qu'en automne et à deux niveaux de profondeur (0-3 et 3-6 cm). Aucune espèce n'a été liée de façon significative à un paramètre donné plus de quatre fois (le plus souvent de 1 à 3 fois). Sept espèces ont accusé des rapports certains dans les deux zones étudiées. Les chiffres les plus élevés des corrélations significatives ont été en relation avec le pH, la saturation en base, le Ca, le Mg et le Mn. Ces paramètres augmentent avec l'augmentation de la fertilité des sols. Quelques-unes des espèces caractéristiques des sols pauvres en humus brut étaient négativement liées à ces paramètres, tandis que certaines « espèces de sol riche » y étaient positivement liées. Les espèces de Collembolles sont des indicateurs peu fiables de la chimie des sols. Des combinaisons d'espèces peuvent cependant améliorer le niveau de précision.

**Mots clef:** Collembola, chimie du sol, forêt de conifères, Norvège.

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**Synopsis:** *Original scientific paper*

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In 25 Collembola species, relationships between abundance and soil chemical properties were studied by analyses of correlation coefficients. Samples were taken from seven different vegetation types in each of two study areas, and the soils ranged from poor podzols to rich brown earth. Soil chemical properties were N, pH, base saturation %, exchangeable Ca, Mg, Mn, Na, K and loss on ignition. In each species, relationships were tested eight times, as samples were taken both in spring and autumn, in two depth levels (0—3 and 3—6 cm) and in two study areas. No species was significantly correlated to a given parameter more than four of these times (most often 1—3 times). Seven species repeated certain relationships in both study areas. The highest number of significant correlations were with pH, base saturation, Ca, Mg and Mn. These parameters increase with increasing soil fertility. A number of species characteristic for poor raw humus soils were negatively correlated to these properties, while certain "rich soil species" were positively correlated. Collembola species are relatively poor indicators of soil chemistry. Combinations of species may, however, improve the level of precision.

**Key words:** Collembola, soil chemistry, coniferous forest, Norway.